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Formulation of Provider R&D Output Metrics for Navy Warfare Enterprises

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PREFACE

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13. ABSTRACT (Maximum 200 words)

In the Navy Enterprise construct, the *warfighter* is responsible for establishing the integrated warfighting requirements, the *provider* is responsible for the processes and intellectual capital that transform requirements and resources into Fleet readiness and capability, and the *resource sponsor* is responsible for providing the means necessary to support the provider. This construct is based on the premise that all three elements must be synchronized and transparent if the required operational capabilities are to be delivered in the most efficient manner.

This report discusses the formulation of provider output metrics for Navy Warfare Enterprises and associated R&D-focused organizations. The Enterprise construct requires that upper-tier enterprises delineate quantified warfighter requirements (metrics with identified units of measure) that constitute the "demand signal" to the provider. Properly constructed demand signal metrics can be used to develop meaningful Warfare Enterprise and provider output metrics. The output metrics need to be based on products and services, and they should not be the measure of activity (i.e., the process). The provider can use time-honored portfolio management techniques to provide measured and/or expected value assessments relative to the warfighter demand signal metrics. Organizational R&D performance output metrics are also discussed.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASN RDA	Assistant Secretary of the Navy for Research, Development, and Acquisition
AT&L	Acquisition, Technical Authority, and Logistics
BOD	Board of Directors
C2F	Commander, Second Fleet
C3F	Commander, Third Fleet
CFFC	Commander, Fleet Forces Command
CNO	Chief of Naval Operations
COMNAVSEA	Commander, Naval Sea Systems Command
CPF	Commander, Pacific Fleet
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiél, Leadership & Education, Personnel, and Facilities
ExCOMM	Executive committee
FAR	Federal Acquisition Register

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

FRE	Fleet Readiness Enterprise
FRP	Fleet readiness plan
FRTP	Fleet readiness training plan
GDP	Gross domestic product
MOE	Measure of effectiveness
MOP	Measure of performance
MPTE	Manpower, Personnel, Training, and Education
NAE	Naval Aviation Enterprise
NAVSEA	Naval Sea Systems Command
NECC	Naval Expeditionary Combat Command Enterprise
NETWAR	Network warfare
NNFE	Naval NETWAR FORCEnet Enterprise
NUWC	Naval Undersea Warfare Center
O&S	Operations and support
ONR	Office of Naval Research
OPEVAL	Operational evaluation
OPNAV	Office of the Chief of Naval Operations
PEO	Program Executive Office
PPP	Purchasing power parity
R&D	Research and development
RDT&E	Research, development, test, and evaluation
ROA	Return on assets
ROE	Return on equity
ROI	Return on investment
S&T	Science and technology
SECNAV	Secretary of the Navy
SWE	(Naval) Surface Warfare Enterprise
SYSCOM	Systems Command
TECHEVAL	Technical evaluation
TYCOM	Type Commander
UARC	University Affiliated Research Center
USE	(Naval) Undersea Enterprise
USFFC	U.S. Fleet Forces Command
USMC	United States Marine Corps
VCNO	Vice Chief of Naval Operations
WC	Warfare Center

FORMULATION OF PROVIDER R&D OUTPUT METRICS FOR NAVY WARFARE ENTERPRISES

1. INTRODUCTION

A metric is a standard of measurement. According to Geisler (reference 1), a metric "is a description of a system of measurement that includes the item being measured, the unit of measurement, and the value of the unit." In his monumental work on science and technology metrics, Kostoff (reference 2) provides a reminder that every "metric and associated data…should have a decision focus; it should contribute to the answer of a question which in turn would be the basis of a recommendation for future action."

This leads to the following necessary steps in constructing metrics (adapted from reference 2):

- Determine what we want to measure
- Determine what we want to achieve with our measurement
- Determine available measures
- As necessary, create combinations of measures such as indexes and integrated measures
- Select methods and instruments for data collection
- Assess the validity, reliability, and amplitude of the metric.

So, to be effective, a metric must have units, be measurable, address a particular question, and be of a form that leads to informed decision making. Without this construct, a metric becomes meaningless.

Implementation of the Navy Enterprise construct has generated considerable discussion pertaining to output metrics. The drive toward output metrics is occurring in parallel with the evolution of the Navy Enterprise construct. Selection of output metrics has been particularly elusive for research, development, test, and evaluation (RDT&E) functions of the Warfare Enterprises. Research and development (R&D) value metrics have traditionally been difficult to generate and measure within the public and private sector technical communities.

This report draws on R&D metrics research as applied to the private and public sectors. Care is taken to investigate whether private sector experience is applicable to the Navy Enterprises. An attempt is made to go back to first principles and adhere to business management terminology. As such, it is not an entering assumption that the measures of Navy Enterprise or Navy Warfare Center effects (i.e., value to the warfighter) will be determinable with a single overarching output metric.

This report begins with a discussion of Navy Enterprises and a perspective on Warfare Enterprise output metrics based on the warfighting value of the *provider* product and services. The second section provides a discussion of R&D metrics as applicable to Warfare Enterprises and concludes with a discussion of provider R&D organization output metrics. The report does not address Navy Enterprise metrics associated with acquisition or industrial operations.

2. NAVY ENTERPRISES

2.1 ENTERPRISE CONSTRUCT

The Navy's alignment to an enterprise construct can be traced to Chief of Naval Operations (CNO) Admiral Vern Clark's proclamation of Sea Power 21 as the vision of how the Navy would "organize, integrate, and transform" (reference 3). Sea Enterprise was introduced within Sea Power 21 as a supporting organizational process with the express purpose of finding organizational and process efficiencies that would result in the savings necessary to recapitalize the Navy and transform it "into a 21st-century force that delivers what truly matters: increased combat capability" (reference 3). The CNO, within his 2003 leadership guidance (reference 4), tasked OPNAV N09/N4 with the establishment of "a Sea enterprise organization and process that coordinates efforts between the Navy Secretariat, USMC, and other Services, to generate corporate efficiencies for reinvestment." The guidance was greatly expanded in 2004 (reference 5) to include the application of the Sea Enterprise principles and the establishment of, among other things, various cost-benefit analyses, savings generation, best practice sharing, and metric programs.* The business of Sea Enterprise has been progressing since.

The Navy Enterprises are based on a construct of *warfighter*, *provider*, and *resource sponsor* relationships as shown in figure 1. The warfighter is responsible for establishing the integrated warfighting requirements. The provider is responsible for the processes and intellectual capital that allow requirements and resources to be transformed into readiness and capability delivered to the Fleet. The resource sponsor is responsible for providing the resources necessary to support the provider (reference 6). The enterprise construct is based on the premise that all three elements must be synchronized and transparent if the required operational capabilities are to be delivered in the most efficient manner (in terms of both cost and schedule).

Figure 1. Navy Enterprise Construct

*In reference 5, the stated Sea Enterprise principles are: (1) Leverage technology to improve performance and minimize manpower costs. (2) Promote competition and reward innovation and efficiency. (3) Challenge institutional encumbrances that impede creativity and boldness in innovation. (4) Aggressively divest non-core, under-performing, or unnecessary products, services, and production capacity. (5) Merge repetitive, redundant, or superfluous costs. (6) Minimize acquisition and life-cycle costs. (7) Maximize in-service capital equipment utilization. (8) Challenge every assumption, cost, and requirement.

The Navy has established a hierarchy of enterprises where each tier is based on this construct. Figure 2 shows the hierarchy promulgated by Commander, U.S. Fleet Forces Command (USFFC) in 2005 (reference 7). The warfighter, resource sponsor, and provider change at each tier in concert with their organizational missions and responsibilities. The warfighter at the lower level enterprise—the Warfare Enterprise—becomes the provider to the next higher level. In this manner, systems and personnel comprise the units (platforms—hulls, airframes, and networks), units comprise Fleets, and Fleets comprise the highest-level Navy response for the nation.

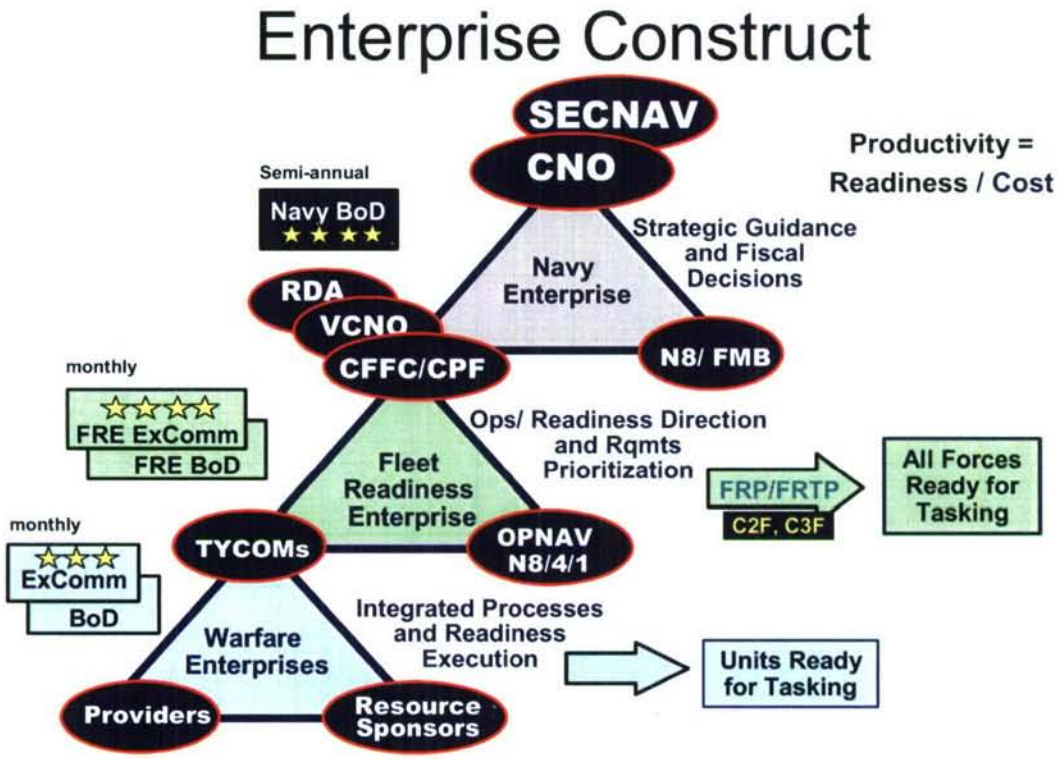

Figure 2. Hierarchy of Navy Enterprises

The Navy has instituted a number of Warfare Enterprises. Currently, the Warfare Enterprise domains are (reference 8):

- Naval Aviation Enterprise (NAE)
- Naval Surface Warfare Enterprise (SWE)
- Naval Undersea Enterprise (USE)
- Naval Expeditionary Combat Command Enterprise (NECC)
- Naval NETWAR FORCEnet Enterprise (NNFE).

As stated in reference 8,

> The primary mission of the five Warfare Enterprises is to deliver warfare capabilities in response to the Navy Component Commander's and Combatant Commander's demand signals while working to enhance effectiveness and efficiency, thereby increasing productivity across their domain and driving out cost.

The multi-tier nature of the Navy Enterprise construct results in the following relationships among the elements, as shown in figure 3:

- The upper tier informs the warfighter in the lower tier of its "demand signal"—i.e., the requirements from the operating forces.
- The warfighter informs the resource sponsor and provider of these needs.
- The resource sponsor works with the warfighter and provider to optimize the delivered products and services within funding allocations.
- The provider provides the warfighter with the products and services as tasked and funded by the resource sponsor.

Figure 3. Enterprise Participant Roles

The strategic objectives of Sea Enterprise are to change culture and behaviors, improve processes and structures, and harvest savings (reference 9). These objectives are to be met by the Warfare Enterprise processes and organizational mission and responsibilities. It is important to understand the level of authority associated with a Navy Enterprise as one of engagement and process improvement through collaboration, coordination, sharing, transparency, and linked metrics. It is not an alternate process for line management command and control responsibilities; therefore, it is not a substitute for the personal authority and responsibility to decide, command,

order, or comply. Commander, Naval Sea Systems Command (COMNAVSEA) guidance relative to the lower-tier Warfare Enterprise summarizes the intent as follows (reference 10):

> Enterprise management is a behavioral model, not a command and control structure. The model facilitates collaboration with all readiness partners and contributing organizations through a structured approach, and helps leadership focus on understanding and managing readiness production, cost, and risk.

As shown in figure 4, the Systems Commands (SYSCOMs) are designated as the lead providers. In this role, the SYSCOM Commanders are responsible for aligning the total contingent of providers consisting of the SYSCOM, SYSCOM-affiliated Program Executive Offices (PEOs), Office of Naval Research (ONR), Defense Advanced Research Projects Agency (DARPA), Warfare Centers, academe, and industry.

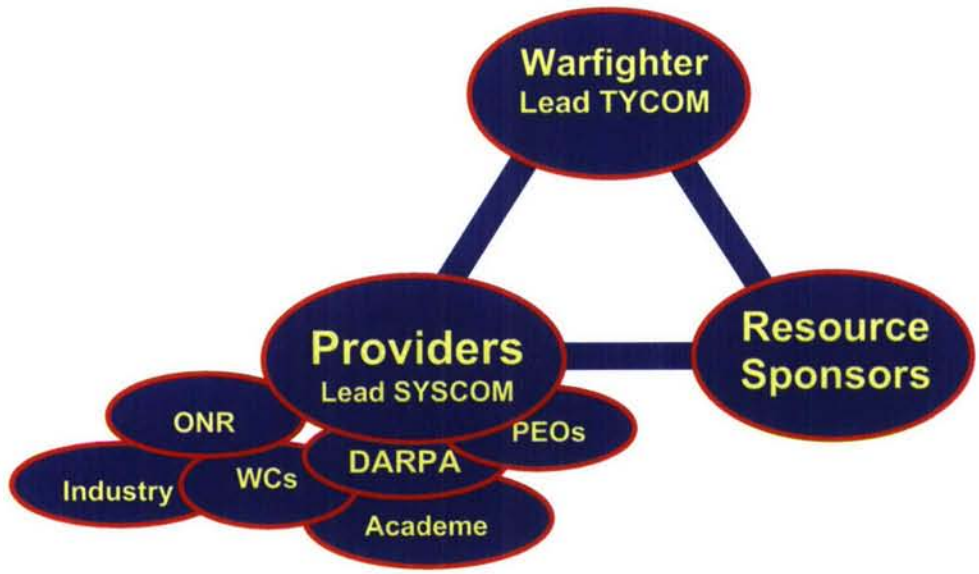

Figure 4. Warfare Enterprise Construct

In December 2006, CNO ADM Michael Mullen directed the establishment of a new Provider Enterprise to address future capability at cost and to support the Fleet Readiness Enterprise for current readiness at cost. The relationship of the Provider Enterprise to the existing enterprises is shown in figure 5. The details of the relationship are still in development. It is unclear what form the lead provider role will be in the Provider Enterprise. It is likely that these providers will heavily overlap with the Warfare Enterprise providers.

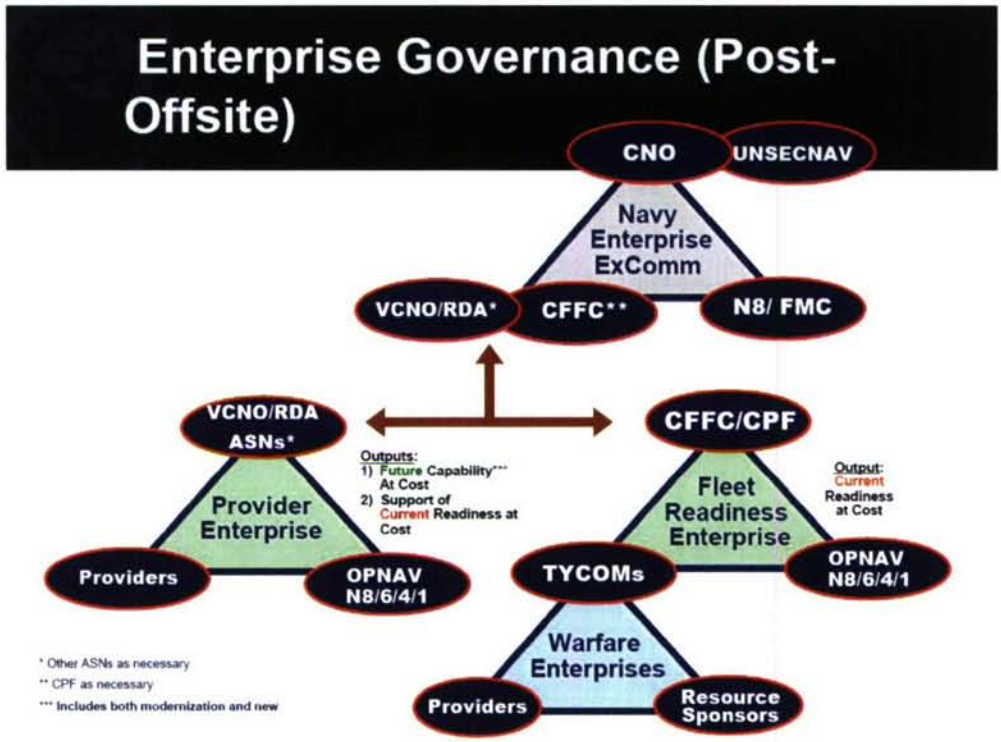

Figure 5. New Enterprise Construct (from reference 11)

2.2 NAVY WARFARE ENTERPRISE DEMAND SIGNAL

2.2.1 Identifying the Demand Signal

The product of the Warfare Enterprises is *units ready for tasking* (figure 2), which is the product the lead TYCOM brings forward as the provider in the Fleet Readiness Enterprise (FRE). This is consistent with the TYCOM role of operating, maintaining, training, and equipping platforms in support of Fleet and National tasking. To meet this role, the full demand signal is composed of all the DOTMLPF (doctrine, organization, training, materiél, leadership and education, personnel, and facilities) elements as they relate to the TYCOM roles. All of these elements must be properly aligned to have an operational capability. As lead provider in the FRE, the TYCOMs have supporting providers, including training commands and other shore infrastructure.

Within the Warfare Enterprise, the "primary Provider/Enabler Elements are Manpower, Personnel, Training, and Education (MPT&E), Acquisition, Technical Authority, and Logistics (AT&L), Installations Management, Health Care, and Science and Technology" (reference 8). Many of these elements are beyond the lead SYSCOM organizational mission and responsibilities. As a result, the Warfare Enterprise provider's primary emphasis is focused on materiél—the "M" in DOTMLPF. In a sense, the provider is an acquisition enterprise.

What does this mean for the required nature of the demand signal? It is incumbent on the warfighter to properly identify the demand signal to the Warfare Enterprises. The demand signal needs to be stated in terms of required operational capabilities, with clearly defined and quantified warfighting metrics (e.g., a certain probability of kill against a particular target in a theater of interest). The demand signal should not be in a single relative term such as maximized readiness at affordable cost. Maximized readiness at affordable cost may not win wars. Affordability is relative to an acceptable level of risk—similar to personal decisions about how much insurance to carry.

Proper warfighting metrics can be translated into terms understandable by the acquisition and R&D communities. Operational capabilities can be translated into technical or system capabilities that form the basis of acquisition/R&D projects and portfolios. The provider can manage to, and report on, the portfolios based on technical or system metrics directly linked to operational capability metrics.

Although the burden is on the warfighter to provide the proper demand signal, it is sometimes necessary for the provider to work with the warfighter to shape the demand signal based on the art-of-the-possible. There is a historical precedence for the warfighter and provider communities to co-evolve requirements.

2.2.2 Current Demand Signal

The enterprise currently defines the output of the enterprise in terms of (reference 7):

Productivity or Output = Readiness/Cost.

Discussions of a single productivity metric have lead to an interpretation that

Readiness/Cost = Units Ready for Tasking/Cost,

where the costs are those not associated with operations and support (O&S). Units become defined as ships or airframes ready for tasking within the appropriate Warfare Enterprise.

This interpretation needs further examination. For illustration purposes, let's assume a fictional ship and submarine-based Warfare Enterprise. Assume a 2005 scenario where, in the best case, all 281 ships are ready for tasking. Assume a representative budget of $26B as the non-O&S budget associated with these ships. This would result in:

Output = Productivity = 1.08e-08 ships/dollar.

What would a measure of nano-ships/dollar mean to the warfighter? Is the implicit metric definition of Units Ready for Tasking/Cost correct? Those advocating a single metric might argue the inverse metric should be used:

Output = Cost/Readiness = Cost/Units Ready for Tasking.

This would not detract from the desire that cost should be kept low for each unit.

Utilizing the values from the previous fictional scenario:

Output = $92,526,690/ship.

This is intrinsically more appealing than nano-ships/dollar. If costs were reduced by an order of magnitude, the value would be $9,252,669/ship. This has an appeal in that it is cost sensitive. But does anyone believe the Navy is actually spending an average on the order of $92,526,690/existing hull? Composite metrics can easily send the wrong message.

This construct would also require a complex set of assumptions. Does *units ready for tasking* mean only existing units? What ships are to be considered as those that are ready for tasking? At what point in the year? What costs should be considered? How are current and future readiness assessed? From a provider perspective, this metric does not capture the SYSCOM intent to show how cost cutting measures are increasing the Navy's buying power.

It is insightful to look at a non-military example where the value proposition of readiness at affordable cost is desired. U-Haul™ is in the business of providing units ready for tasking. U-Haul's value proposition to the prospective customer can be summarized as new, safe, reliable, and "meets your needs" equipment (right capability), accessibility to many assets and locations (right time), and affordability (right cost).* As a customer, you weigh these individual values relative to your needs. As a customer, you need multiple metrics to determine if you will be able to achieve your desired effects with the available equipment and at affordable prices. The complexity of the business precludes using a single metric.

Similarly, personal investment decisions do not rely on a single metric to understand a company—its value proposition, earning potential, and historic trends. To do so would misrepresent the risks that need to be addressed by the decision maker.

Likewise, Warfare Enterprise risk assessment cannot be achieved via a single metric—the nature of the business does not allow it. The bottom line is that the current output construct is of limited value to the Warfare Enterprise decision makers. Senior Navy leadership, similar to their corporate peers, needs to understand and manage to complex and multiple business metrics.

The warfighter demand signal must be in terms of capabilities made available to the operating forces based on correct and affordable DOTMLPF. The resulting enterprise output metrics should be in terms of operational capabilities and risk.

*Value proposition was derived from advertising at www.uhaul.com .

2.3 WARFARE ENTERPRISE PROVIDER VALUE PROPOSITION

The lead provider of each Warfare Enterprise is a lead SYSCOM. Each SYSCOM desires to provide value to the Navy in the manner expressed by COMNAVSEA (reference 6):

> Vision: Be a responsive, effective and efficient provider for the Navy Enterprise.
> Mission: Put the right capability in the hands of the warfighter at the right time at the right cost.

In addition, the SYSCOMs are under pressure to find ways to drive down costs (reference 8) and thus improve the Navy's buying power. These are not as directly related as they may initially seem, since the SYSCOMs can only provide those products and services that have been appropriated by Congress and signed into law.

2.3.1 Right Capability, Right Time, Right Cost

The appropriateness of the provider-delivered products and services (right capability, right time, right cost) is subject to:

- OPNAV interpretation of Fleet requirements in the budget submittal
- Whether the quantities being procured are sufficient to provide a warfighting capability (capacity)
- Congressional determination of requirements and capacity via power of the pen and purse (earmarks)
- Actual delivery of the appropriated products and services within performance, cost, and schedule.

The SYSCOM can control only the last of these factors, and it has extensive experience in management controls to measure success or failure. The warfighter and resource sponsor need to address the first two factors. Although held accountable by the warfighter, the SYSCOM—for the reasons given above—cannot control success in delivering the right capability at the right time and the right cost.

The right cost is based on the perceived value of the product or service by many. SYSCOMs can establish performance/cost goals and hope (1) that the market can or is willing to deliver and/or (2) that the Government acquisition and oversight functions can be delivered to these goals. SYSCOMs have experience in measuring progress toward meeting performance/cost goals.

Thus, the Warfare Enterprise needs to establish warfighting success and risk metrics for the program of record and proposed acquisition options. These metrics should clearly show the performance based on warfighting mission effectiveness, warfighting risk, and cost based on program cost, performance, schedule, and risk. This has an additional benefit—it allows the Warfare Enterprise to show the impact of decisions made outside of its control.

This approach leads to metrics of the form:

Output = Performance/Cost.

The provider should establish metrics that entail product (system) or service (process) measures of performance that feed the warfighting measure of effectiveness—classic cost/benefit measures.

2.3.2 Improved Buying Power

In the private sector, the consumer gains buying power if:

- Corporations elect to lower selling prices to increase profits through higher volume sales
- Corporations elect to maintain the same profit margin but lower prices as manufacturing costs are reduced through lowered material costs or improved manufacturing efficiencies
- Corporations reduce selling price and reduce profit margins—an undesirable condition for a profit-based business.

The SYSCOMS and affiliated PEOs face similar conditions:

- Will budget appropriations support higher volume purchases at reduced unit cost? This is not within SYSCOM control.
- Are corporations willing and able to lower prices any further? Are they already at minimum levels acceptable to their shareholders? This is not within SYSCOM control, but reduced costs through efficiency improvements can be encouraged through incentives.
- Are there new technologies or processes that would reduce manufacturing costs? This is not within SYSCOM control; however, the technology organizations within the enterprise can address this topic. SYSCOMs can encourage this research through funded tasking and/or incentives.
- Are there efficiency improvements to be had within the Government acquisition and oversight process? This is within SYSCOM control as constrained by the Federal Acquisition Register (FAR) and other regulations.
- Are the requirements behind the acquisition more stressing than required by the Fleet? Are the cost drivers behind the requirements fully understood? This is not within SYSCOM control, but the SYSCOM can work within the Warfare Enterprise to validate existing requirements.

The results of any of these actions lend themselves to reporting the potential for improved "buying power" via:

- Cost reduction due to requirement relaxations (based on cost, performance, and risk assessments).
- Cost savings due to Government efficiencies without the compromise of inherently Governmental functions.
- Cost savings and cost avoidance due to technology infusion.

Each of these cost reductions positively impacts metrics in the form of performance/cost.

3. NAVY WARFARE ENTERPRISE R&D

The Warfare Enterprise provider must respond to the readiness demand signals for the current Navy, the future Navy, and the Navy-after-Next. This necessitates that the provider engage in activities that span the full spectrum from science and technology (S&T) to operational system support. The provider meets these time-evolving demands through parallel S&T, R&D, and acquisition "pipelines." From an R&D perspective, the pipeline must contain a balanced portfolio of rapid-transition applied research and long-term research.

As shown in figure 6, these pipelines transition different output products. At any point in time, the provider is providing the following output products:

- Acquisition Community – Transition of purchased material to the current Navy
- R&D Community – Transition of technology into the acquisition community for future Navy systems or current Navy system improvements
- R&D Community – Transition of basic research to applied research for future Navy and Navy-after-Next systems.

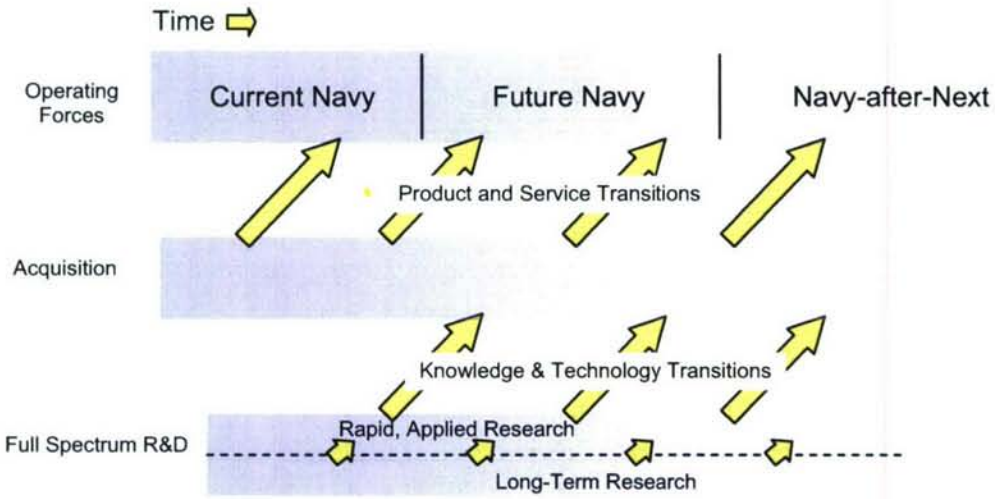

Figure 6. R&D and Acquisition Transitions

Provider output metrics need to be consistent with these output products. For example, the acquisition community must be able to provide measured system performance values that the warfighter can use to determine or measure operational capability performance. The R&D community must measure technology performance that can be used to determine the expected value of systems that incorporate this technology. The warfighter can use these values to determine the expected operational capability if the technology is successful. Provider output metrics need to account for the fact that each output product is different and will have a different effect on operational capability or risk reduction.

3.1 PARALLELS WITH INDUSTRY R&D

The Warfare Enterprise is a collection of team members and collaborative processes used to align the people, dollars, and programs associated with a warfighter area (e.g., Undersea Warfare) (reference 6). Industry is different in that it does not separate its "resource sponsor" from its R&D. The industrial relationship between functional units of business (e.g., manufacturing, R&D, marketing) and its customer has been extensively studied. This is the field of R&D management.

The provider's need for R&D necessitates a look at the relationship of R&D functional units to the other business units and the customers. Relationship changes between the business units have evolved into recognized generations of R&D management. The generation nomenclature can be traced back to the mid-1990s and can be defined as follows (see appendix A for a more comprehensive definition):*

> Generation 1. R&D is an overhead function insular to and independent of the corporation's strategic framework. The R&D function is to develop technologies that may or may not be consistent with the business's strategic direction and goals. Technology push is the prime emphasis.
>
> Generation 2. R&D remains insular but becomes less independent and begins to be aligned with marketing strategies. Managing technology "pull" begins to address particular product development strategies (needs pull). The R&D function is managed on a project-by-project basis.
>
> Generation 3. Senior leadership and functional managers together develop the business plan and model based on the corporate strategy. Strategically-balanced R&D portfolios across the corporation are developed based on technology development roadmaps and product life-cycle considerations.
>
> Generation 4. Simultaneous technology push and pull based on tight integration of leading customers in the evolution from concept to development. Competitiveness is dependent on the technical knowledge and capabilities within but also outside of the company. R&D management, from necessity of speed, goes beyond technical product and process to include business and market models that encompass management of knowledge, technology, and market/industry infrastructure.
>
> Generation 5. The management of information, knowledge and innovation is based on broad horizontal network processes that are cross-border and that rely heavily on information technology. This broad network is operated based on strategic partnerships that ensure overall organizational and systems integration. Developers, manufacturers, and customer collaborate in defining the way forward and the subsequent research.

*This description of R&D management generations relies heavily on those presented in references 12 and 13.

An initial reaction might be the desire to aspire to the newest generation of R&D management. It should be noted that the newer generations apply to product areas that are subject to extremely rapid technology changes and intense competition based on customer demand for new products that include these technologies, e.g., consumer information technology products such as cell phones. Industries based on advanced technology and hypercompetitive market demand product areas more tightly couple R&D to marketable endproducts as a result of significant customer interaction. This tight coupling is known by many names, including "open innovation" (reference 14).

Associated with advanced R&D management generations is a recognized danger that must be managed. The tight coupling of R&D in a competitive climate has led to an emphasis on rapid transition (and, thus, rapid applied research) at the expense of longer-term technology research. This course leads to a long-term exposure to competitors if decision makers do not maintain a proper balance of short- and long-term research in their R&D portfolio.* From a military perspective, this competition might result in losing technological advantage to future adversaries.†

Not every product area needs to be generation 5. It is probably safe to assume that the Warfare Enterprise primarily operates at the generation 3 level across its product areas, with tails to generations 2 and 4. As lead provider, the SYSCOM must take the lead in establishing the appropriate level of R&D management within the Warfare Enterprise business model. More advanced R&D management generation requires greater adherence to the principles of open innovation and establishes the required nature of the relationships and concept of operation between the warfighter, resource sponsor, and provider.

3.2 NAVY WARFARE ENTERPRISE R&D OUTPUT METRICS

3.2.1 Measuring R&D and the Impact of the R&D Product

Within the military context, the ultimate purpose of R&D is to broaden and deepen military warfighting capabilities. At the next lower level, the purpose of U.S. federally funded R&D is to:

- Gain knowledge or understanding of scientific principles with presumed broad application to needs and requirements
- Determine the means by which specific needs and requirements may be met through new technologies or knowledge
- Apply knowledge to the creation of new and improved processes, products, and services that meet specific needs or requirements.‡

*Many references exist; one example is reference 15.

†Much has been written over the last few years on the potential erosion of U.S. technological advantage. For examples, see references 16 and 17.

‡These are an adaptation of definitions for basic research, applied research, and development from reference 18.

To develop R&D metrics, it is important to understand the actual R&D output product. Roussel et al. (reference 19) state:

> R&D produces one product only – knowledge. True it is knowledge with a purpose, but it is still just knowledge. R&D does not produce a physical product for sale or an operating process. It does not produce a new business. Nor does it produce quality. However, R&D does produce the know-how at the foundation of all these other results.
>
> In almost all companies across the world, the know-how developed by R&D must be translated by management action into products, processes, cost reductions, quality improvements, conformance with environmental regulations, support of product claims, and other objectives. Rarely is this know-how created strictly for sale.
>
> In short, R&D seeks out the location of the treasure, but senior business management holds the key to it. Only management can mobilize all of the resources necessary to transform an R&D result – knowledge – into a commercially useful result. Only management can provide support from marketing, manufacturing, or capital. Only management can enforce the company's vision and strategies and involve all functions – including R&D – in their successful implementations.

Relative to the public sector, Kostoff (reference 2) states:

> Public-sector S&T sponsors have two major responsibilities: a) to sponsor high quality S&T that has high potential for eventually being used to improve systems and operations of the sponsor's stakeholders/customers for national benefit, and b) to make the downstream developers/acquisitioners of these final products aware of global S&T being performed that could impact their downstream development and acquisition. These S&T sponsors have little control over the fate of their sponsored S&T after the S&T is completed, and especially after the S&T transitions to other organizations for further downstream development and acquisition. Some of the many external factors that determine the eventual fate of S&T other than technical quality include geopolitical, local political, economic, financial, legal, environmental, cultural, etc. The only control the S&T sponsors can actually exert over potential applications is to produce a high quality product that has positive transitionability characteristics (e.g., affordable, maintainable, reliable, addresses stakeholder and customer need, high technical quality, etc). *Succinctly, S&T sponsors control outputs, not outcomes.*
>
> Yet, present metrics systems for evaluating public sector S&T sponsors do not address the reality of the two responsibilities described above. Public sector S&T sponsors are held accountable for both outputs and outcomes. Many public sector S&T sponsor evaluations contain metrics that address downstream outcomes. Public sector S&T sponsors are held accountable, to some degree, for S&T products that do not transition for further development, or that do not eventually result in envisioned outcomes. This is an example where *the appropriateness of the metric is perhaps more important than its measurement capability*.

The parallel to the Warfare Enterprise is in the method by which "technology" actually transitions to the Fleet. In reality, technology transitions only when it is incorporated into a system purchased for the warfighter. Due to performance-based procurement regulations, the vendor providing the material has the latitude to determine which technologies are utilized. The vendor may or may not elect to use technologies developed by Navy S&T or R&D. Technology transition agreements notwithstanding, there is no guarantee that a particular technology will be manifested in acquisition system designs.

The R&D conducted by the Navy serves a number of purposes. It explores technology possibilities not necessarily deemed to have a sufficient return-on-investment (ROI) for commercial purposes. It allows exploration of proof of concept, which provides the warfighter an understanding of the realm of the possible. It provides the acquisition agent the knowledge from which to develop specifications, make smart buyer decisions, and monitor the progress of the vendor. Representative of Kostoff's observations, Navy R&D's only guaranteed product is knowledge, and it is the purpose of the collective Warfare Enterprise (provider, warfighter, and resource sponsor) to transition this knowledge into processes, products, and services. Within the enterprise, transition is a collective effort requiring collective responsibility and accountability.

Business management literature discusses the value of R&D and the success of R&D as separate items. The value is related to the effect of the R&D application on the end-user. Value metrics are measures of effectiveness (MOEs). Success is related to the extent to which the specific R&D project objectives are met. Success metrics are measures of performance (MOPs).*

3.2.2 Value MOEs

Many successful generation 3 and 4 organizations manage R&D through the management of an R&D portfolio that is linked to corporate goals. The projects within the portfolio are selected based on the expected value of the new technology in meeting needs or requirements. Researchers such as Geisler are careful to differentiate expected value between the private and public sectors. Expected value in the private sector is based on perceived market share, profits, and return on equity (ROE) or return on assets (ROA). Expected value in the public sector is based on contributions to society and the economy (reference 1). In the public sector, societal benefits (e.g., national defense and environmental safety) can have a greater weight than maximizing financial returns.

There are numerous methods for assessing the expected value of R&D portfolios. Many are based on the population of some form of potential reward versus risk chart (reference 19). One variation is the capability-performance potential versus transition probability chart developed as part of the RAND PortMan Decision Framework (figure 7), which is taken from reference 20. (Reference 20 reports on the RAND adaptation of its framework for ONR.)

*Kostoff (reference 2) uses the term "outcome" to describe the value metric and "output" to describe the success metric.

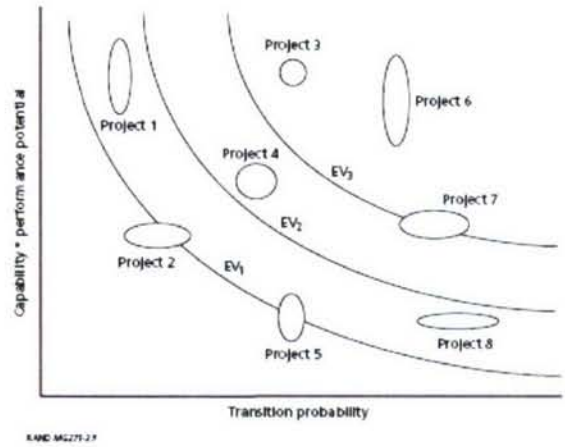

Figure 7. RAND PortMan Decision Framework (from Reference 18)

The RAND framework allows the placement of R&D projects in a common context, which permits evaluation of the individual and collective expected value. The R&D portfolio manager (or potentially a Warfare Enterprise Board) can readily see the attributes and emphasis of the portfolio. Is it a collection of high transition probability, incremental improvements? Is it a balanced mix of high transition probability, incremental improvements, and higher risk but paradigm-changing improvements? Does the R&D have the potential of meeting the warfighter's expectations?

There are many techniques and criteria that could be used to determine how and where a project should be mapped on a reward versus risk chart. The referenced RAND work provides one technique and, as an example, the RAND criteria are provided in appendix B.

3.2.3 Success MOPs

The value metrics are based on an input of success metrics. Success metrics are a measure of how well the project is performing to its R&D objectives. The R&D objective might be an evaluation of the level of performance achievable from various technologies or algorithms, or it might be a proof-of-concept evaluation or a technology demonstration for a system. Success metrics are not a determination of the ultimate success of the R&D output to the end-user. This is a difference akin to the technical evaluation (TECHEVAL) and operational evaluation (OPEVAL) construct used by the DoD. Whether a system employing the R&D ultimately has warfighter-sanctioned operational value is ***not*** an R&D success MOP by this construct.

Table 1 is an example of individual R&D project evaluation criteria. The contents of the table are an adaptation from Roussel et al. (reference 19). The criteria address the assumed benefits of a successful project, the probabilities of achieving this success, project management cost and schedule, etc. These items are standard criteria familiar to project managers.

Project attractiveness elements are the project linkage to the warfighter demand signal. If the warfighter demand signal is properly stated in quantified operational capability terms, the R&D community can work with the warfighter to translate the operational capabilities into technical or system capability terms recognizable by scientists and engineers. Subsequently, the R&D project objective defines the relationship of the project to the technical or system capabilities requirements. Done properly, a project works with the operational analysis community to link the project results with expected operational capability improvements.

Table 1. Potential R&D Project Evaluation Criteria*

Evaluation Criteria	Measure
Project Attractiveness	
Fit with enterprise strategy	A judgment ranging from **excellent to poor**
Inventive merit and strategic importance to the enterprise	The potential power of the sought-after result to: • Improve U.S. technological advantage • Apply to more than one warfare area • Provide foundation for the future Navy A judgment from **high to low**
Durability of U.S. technological competitive advantage	**Years** - If the R&D result can be quickly and easily initiated by adversaries, the project is less attractive than one that provides a protected, long-term advantage
Reward	Usually **performance/cost benefit**, but sometimes "necessity work" (e.g., regulatory) or building a knowledge base that becomes the foundation for transitions (next level of R&D or acquisition)
Competitive impact of technologies	**Base, key, pacing, embryonic** in nature (technology readiness level)
Project Uncertainty	
Probability of technical success	**Probability** that the objective will be achieved as desired
Probability of end-user success	**Probability** of end-user success if the project is technically achieved (i.e., meets operational requirements)
Probability of overall success	**Probability** - The product of the technical and end-user probabilities
Project Exposure	
R&D costs to completion or key decision point	**Dollars**
Time-to-completion or key decision point	**Time**
Cost required to exploit technical success to ready for transition	**Dollars**

*Adapted from Roussel et al. (reference 19).

3.2.4 Warfare Enterprise R&D Metric Hierarchy

The result of the above discussion is that there is a hierarchy of R&D metrics for the Warfare Enterprise, as shown in table 2, that needs to be developed and managed at the Warfare Enterprise level.

Table 2. Hierarchy of Warfare Enterprise R&D Metrics

Level of Evaluation	Nature of Metrics	Current Navy	Future Navy	Navy-After-Next
Warfare Enterprise	Enterprise output linked to demand signal	Improvement in warfighting MOE (measured/expected value)	Improvement in warfighting MOE (expected value)	Improvement in warfighting MOE (expected value)
Lead Provider	Enterprise provider output & execution	Assessment of engineering development portfolio	Assessment of advanced development portfolio	Assessment of technology (S&T) portfolio
Provider	Project output & execution	• Cost • Performance • Schedule • Risk	• Cost • Performance • Schedule • Risk	• Cost • Performance • Schedule • Risk

3.3 PRODUCTIVITY AND R&D ORGANIZATIONAL METRICS

3.3.1 Productivity, Efficiency, Effectiveness

The Warfare Enterprises have spent a considerable amount of time trying to develop a single output metric based on the concept of productivity. This section addresses the concepts of productivity, efficiency, and effectiveness and the accepted definitions and metrics for these terms.

First, some definitions (from reference 21):

- Productivity is the creation of goods and services to produce wealth or value.
- Efficiency is the effective operation of a business or performance of a business task with minimum wasted effort (time, energy, money).
- Effectiveness is production of the desired results.

In short, productivity is about the use of resources, efficiency is doing things right, and effectiveness is doing the right things (reference 22).

Warfare Enterprise provider productivity is based on delivering value to the warfighter through the enterprise's products and services. The provider value comes from being effective in delivering innovation, transitioning products and services, and stewarding capabilities, while maintaining cost effectiveness through business efficiencies.

Productivity also has a more formal economic definition. Sharpe (reference 23) writes:

> Productivity is the relationship between the output of goods and services and the inputs of resources, human and non-human, used in the production process, with the relationship usually expressed in ratio form.

The ratio form of the definition is: Productivity = Output/Input. It is obvious why the Warfare Enterprise selected a productivity ratio of production of readiness/cost.

The concept is good but further exploration of productivity as a metric is required. In economic terms, productivity is a measure of output quantities to input quantities. Productivity plus pricing factors determine profitability (reference 22). All else being equal, increases in productivity result in increased profitability, which increases economic growth and, thus, the standard of living.

An example of a productivity metric is the gross domestic product (GDP) per capita, which is a measure of the monetary value of a country's goods and services produced in a year (output)/number of working people (input). For the members of the International Monetary Fund in 2005, this metric results in a range from $69,800/capita for Luxembourg to $596/capita for Malawi (reference 24). There is no right absolute value to achieve. The measure is used for comparison of one country relative to another. The relative comparisons are frequently used to establish national economic policies geared toward improving or maintaining certain standards of living.

There are comparable business metrics that take the form of output/input. Some use *billable hours/full time employees* or *revenue/full time employees*. These are not applicable to the Warfare Enterprise since its mission is not profit-oriented and not to maximize revenue. Others use *tasks completed/full time employee* or *quantities met/full time employees*. These are applicable metrics where repetitive tasks or "piece part" work is the order of business. This may apply to Warfare Enterprise depot work and other industrial operations, but not to the enterprise's R&D work.

Looking at efficiency metrics, it is useful to examine non-profit organizations. If you want to make a choice of donating to one of three charities that perform the same mission, you would presumably choose the charity that maximizes the use of its funds for charitable services. This is the efficiency of the charity (presumed by many to also be a measure of its effectiveness). Charities are rated according to a *charity efficiency rating*, where

Output/input = funds toward mission/funds toward administrative functions.

Shown below are some charity efficiency ratings for 2004 (reference 25):

- Public Broadcast Service 96%
- American National Red Cross 91%
- United Way 88%
- Habitat for Humanity 82%
- National Public Radio 78%
- American Heart Association 75%
- Museum of Fine Art, Boston 64%

The differences in these ratings indicate that it is a personal decision, probably subjective, as to what constitutes perceived value from a donation.

It is important to note that different charity types have different demands and levels of administrative expense. The following is an example of median charity efficiency ratings for two types of charities:

- Food Banks median 94%
- Art museums median 71%.

Thus, it is important to understand what relative efficiency is reasonable for a particluar type of non-profit business.

3.3.2 Relationship to Warfare Enterprise Providers

The efficiencies (direct cost associated with delivering products and services/total costs) of different provider business units should also be different and consistent with the type of business function. Repetitive, task-oriented units such as depots and shipyards strive for very high efficiency ratings. R&D is non-repetitive by nature, so its efficiencies should be lower.

Intuitively, the efficiency of industry R&D should be higher than university R&D (see figure 8). Industry desires to transition its entire R&D and maximize profit. In general, the prime motivation for university R&D is knowledge—not profit. In the DoD, the efficiency of the Warfare Centers and University-Affiliated Research Centers (UARCs) should conceivably fit somewhere between that of industry and universities, since transition is important but so is the conduct of necessary research not deemed profitable by industry or of interest to universities.

Similar to charities, it is important to recognize where a non-profit R&D organization should be positioned. If the Warfare Center/UARC efficiencies get too high, it is probably indicative of (1) cost cuttings that have a long-term impact on R&D health, (2) a concentration on low-risk R&D, and/or (3) other factors that jeopardize the stewardship of technical capabilities necessary to maintain technical authority. If Warfare Center/UARC efficiencies are too low, it is probably indicative of (1) a concentration on high-risk, long-term R&D, (2) a lack of propensity to transition, and/or (3) other factors that jeopardize the mission of providing value to the warfighter. The Warfare Centers/UARCs need to manage their efficiencies within a band. More efficiency is not always better given the organizational mission and value proposition.

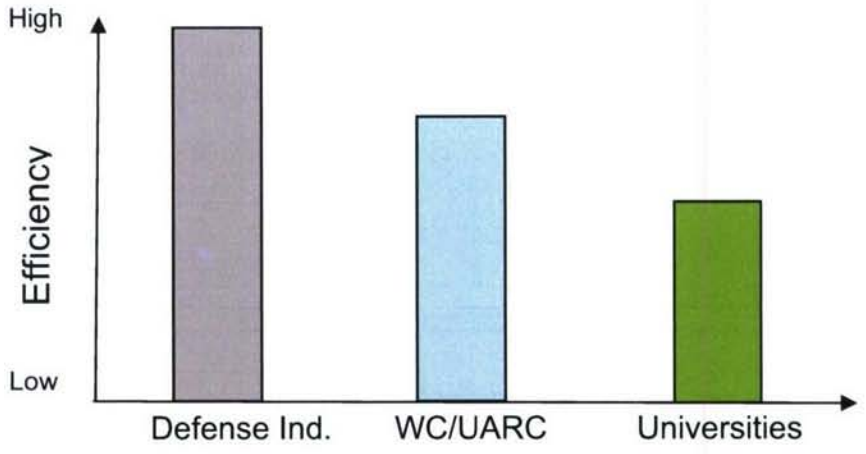

Figure 8. Relative Organizational R&D Efficiencies

Very preliminary analysis indicates that recent "cost-saving" initiatives at the Warfare Centers, as illustrated in figure 9, may be too extreme. This figure shows efficiency ratings for five of the top defense industries, the NAVSEA Warfare Centers, and universities.

The university rating is the U.S. national average (reference 26). Understandably, there are high costs associated with university research facilities and libraries, as well as other administrative costs.

The defense industry rating is based on a "back-of-the-envelope" calculation for direct costs/indirect costs from corporate annual reports.* One could argue that the decreasing efficiencies for the defense industries listed in figure 9 are correlated to the increasing percentage of R&D performed by the individual corporations. A rigorous analysis would be required to determine an exact average for defense industries.

The Warfare Center rating is for the NAVSEA Warfare Centers.

The preliminary data suggest that, given the R&D nature of its business, the NAVSEA Warfare Centers have gone too far with cost cutting. Short-term cost cutting can be managed, but long-term cost cutting in the name of cost savings can be detrimental.

From an organizational perspective, productivity should not be confused with efficiencies that result in cost savings and cost avoidance. Warfare Enterprise providers, in particular the R&D elements, must carefully avoid short-term cost cuttings—deemed cost "savings"—that might jeopardize the provider's long-term ability to maintain technical authority.

*These include the Anteon International 2004 annual report, General Dynamics 2005 annual report, Boeing 2005 annual report, Lockheed Martin 2005 annual report, and Teledyne Technologies 2005 annual report.

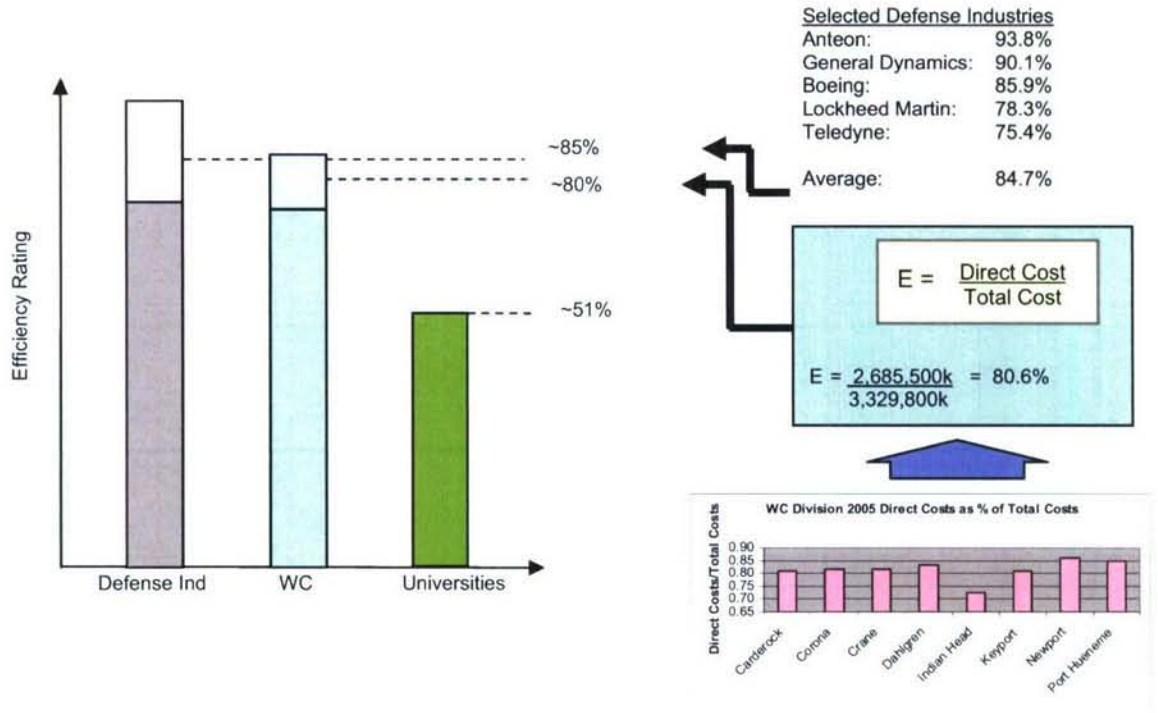

Figure 9. Preliminary Efficiency Data

4. CONCLUSIONS

This report has discussed the formulation of provider output metrics for Navy Warfare Enterprises and associated R&D-focused organizations. The Navy Enterprise construct requires that upper-tier enterprises delineate quantified warfighter requirements (metrics with identified units of measure) that constitute the "demand signal" to the provider. Properly constructed demand signal metrics can be used to develop meaningful Warfare Enterprise and provider output metrics. The existing concept of maximized readiness at affordable cost is a universal good, but a single output metric for the *readiness/cost ratio* cannot be developed in any meaningful form. Units of measure cannot be assigned to the ratio, nor would the resulting value provide any meaning to a decision maker. The output metrics need to be based on products and services and should not be a measure of activity (i.e., the process). The provider can use time-honored portfolio management techniques to provide measured and/or expected value assessments relative to the warfighter demand signal metrics.

Also discussed was organizational R&D performance output metrics. Productivity should not be confused with efficiencies that result in cost savings and cost avoidance. Warfare Enterprise providers, in particular the R&D elements, must carefully avoid short-term cost cuttings—deemed cost "savings"—that might jeopardize their long-term ability to maintain technical authority.

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APPENDIX A
GENERATIONS OF R&D MANAGEMENT

GENERATION 1

R&D is an overhead function insular to and independent of the corporation's strategic framework. The R&D function is to develop technologies that may or may not be consistent with the business's strategic direction and goals. Technology push is the prime emphasis. Leave the R&D laboratory alone and good things will eventually happen. This will generate new products for the business. Rely on "legacy" products until the breakthroughs occur.

GENERATION 2

R&D remains insular but becomes less independent and begins to be aligned to marketing strategies. Managing technology "pull" begins to address particular product development strategies (needs pull). The R&D function is managed on a project-by-project basis. An integrated corporate view is difficult to obtain and corporate priorities across projects are hard to establish; in fact, it is hard to establish priorities within business sectors. Marketing develops new ideas and R&D delivers the product. Business management literature refers to this as being a past generation; many companies still practice this generation.

GENERATION 3

This is the first generation that is based on corporate strategy. Senior leadership and functional managers together develop the business plan and model based on the corporate strategy. Strategically balanced R&D portfolios across the corporation are developed based on technology development roadmaps and product life-cycle considerations. R&D develops new ideas, and market feedback refines the product. This partnership of general and R&D managers ensures that R&D provides the product needed to meet the corporate strategy. Most advanced R&D corporations manage to the generation 3 model. This is also referred to as the coupling of technology push and pull.

GENERATION 4

Generation 4 begins the adaptation to the pace of new technology development cycles and the competitive pace of new products that exploit these cycles. There is simultaneous technology push and pull based on leading customers tightly integrated in the evolution from concept to development. Competitiveness is dependent on the technical knowledge and capabilities within but also outside of the company. Knowledge base (repository for, integration of, and body of) is the critical component of the company. This broad knowledge base allows for simultaneous and parallel innovation versus the serial innovation that is the basis of the first three generations. Discontinuous (disruptive) innovation is desired. R&D management, from

necessity of speed, goes beyond technical product and process to include business and market models that encompass management of knowledge, technology, and market/industry infrastructure. Dynamic, proactive, and energetic management and business models are key aspects of this generation. Generation 4 management is not widely found.

GENERATION 5

Generation 5 takes Generation 4 to another level of emphasis on flexibility and speed of development. The management of information, knowledge, and innovation is based on broad horizontal network processes that are cross-border and that rely heavily on information technology. This broad network is operated based on strategic partnerships that ensure overall organizational and systems integration. Knowledge base and collaboration are key attributes. Developers, manufacturers, and customer collaborate in definition of the way forward and the subsequent research. Generation 5 management is still emerging.

APPENDIX B
EXAMPLE OF R&D PORTFOLIO ASSESSMENT CRITERIA

Note: The material in this appendix is taken from appendix C of reference 18.

APPENDIX C

Value Descriptions and Scales

Value of S&T projects will be based on three factors:

Value = Capability × Performance Potential × Transition Probability

Each factor will be estimated based on answers to the following questions:

Capability

The capability that the project is aimed at achieving will be evaluated based on its importance, at a specified level of performance, to a specific warfighting scenario, as well as the extent to which it influences other important scenarios.

Assuming the project is fully successful, the resulting capability would be:

- ☐ Critical to success in the scenario
- ☐ A major factor for success in the scenario
- ☐ Helpful to success in the scenario
- ☐ Not relevant to or possibly detrimental to success in the scenario

How would you assess the applicability of this resulting capability across important scenarios?

- ☐ Pervasive across many scenarios
- ☐ Useful in a number of different scenarios
- ☐ Applicable to a very limited number of scenarios similar to this one

Performance Potential

The performance potential will be evaluated based on the extent to which the project may provide performance consistent with achieving the required capability.

Assuming the project is fully successful, the performance needed to achieve the required capability for the scenario would be:

- ☐ Fully achieved
- ☐ Partially achieved
- ☐ Hardly achieved at all

Assuming that the project is fully successful, the performance described above would be achieved under:

- ☐ All relevant scenario conditions
- ☐ Most relevant scenario conditions
- ☐ Some relevant scenario conditions
- ☐ A limited number or none of the relevant scenario conditions

Transition Probability

The transition probability will be evaluated based on the quality of the transition plan and the difficulty of remaining technical and fielding problems.

The project and project team is presently characterized as:

- ☐ No remaining technical problems; experience fielding similar technology
- ☐ Remaining technical problems; experience fielding similar technology
- ☐ No remaining technical problems; no experience fielding similar technology
- ☐ Remaining technical problems; no experience fielding similar technology

The transition plan for this project is:

- ☐ Well conceived and appears to be implementable
- ☐ Has some problems with cost, schedule, or other fielding burdens
- ☐ Has major problems with cost, schedule, or other fielding burdens
- ☐ Is severely flawed or nonexistent

Capability Scale

	Pervasive	Number of Different	Limited Number
Critical	5	4	3
Major Factor	4.5	3.5	2.5
Helpful	4	3	2
Not Relevant	3	2.5	1

Performance Potential Scale

	Fully	Partially	Hardly At All
All	5	4	2.5
Most	4	3	2
Some	3	2.5	1
Limited or None	2	1	0

Transition Probability Scale

	No Technical Problems Experience Fielding	No Technical Problems No Experience Fielding or Technical Problems Experience Fielding	Technical Problems No Experience Fielding
Implementable	5	4	3
Some Problems	4	3	2
Major Problems	3	2	1
Severely Flawed	2	1	0

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